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Refraction Seismic Investigations Rosiclare Fluorspar District, Illinois


Part 1. — Goose Creek Area

Robert B. Johnson

DIVISION OF THE
ILLINOIS STATE GEOLOGICAL SURVEY
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REFRACTION SEISMIC INVESTIGATIONS ROSICLARE FLUORSPAR DISTRICT, ILLINOIS

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ABSTRACT

This investigation along a portion of the Goose Creek fault in northeastern Hardin County was undertaken to determine how effective the refraction seismograph may be in locating faults along which much of the fluorspar occurs in the Rosiclare fluorspar district.

The seismic data, obtained by standard reversed-profile refraction shooting, have been correlated with subsurface geologic data obtained from core drilling. The exploratory work was divided into two parts: (1) determination of characteristics of seismic data in selected faulted areas where geologic control is good; and (2) comparison of seismic results in areas where drill core information was obtained subsequent to the seismic survey.

The fault-produced obstructions to the normal passage of dynamite-created elastic waves through the earth are recorded by seismograph. Further investigation with the seismograph in the district is necessary before detailed information about a fault, such as the amount of displacement, may be determined from the seismic data. Alternation of lithologies (limestones, sandstones, shales) in subsurface strata introduce difficulties in locating faults on the basis of seismic data.

INTRODUCTION

The Illinois-Kentucky fluorspar district leads in the United States production of fluorspar, a mineral important in the steel, aluminum, and chemical industries. In Illinois, fluorspar (calcium fluoride, CaF_2) is mined chiefly from vein deposits in the Rosiclare district and bedded deposits in the Cave-in-Rock district. These districts are in Hardin County, southeastern Illinois (fig. 1). Additional deposits are found in adjacent parts of Pope and Saline counties.

Fluorspar mining is important to the economic stability of southern Illinois. Known deposits have been extended and new deposits discovered by means of drilling and the use of surface geologic mapping. Geophysical exploration methods have been used in the Illinois-Kentucky district over the past 30 years in an effort to determine their usefulness in the search for fluorspar. The principal methods used have been the electrical earth-resistivity method and the electrical self-potential method (Hubbert, 1944; Lee and Hemberger, 1946; Weller et al., 1952).

The Illinois State Geological Survey has pioneered in the use of the refraction seismograph in the fluorspar district. This investigation was undertaken partly because of the economic importance of developing techniques to



Fig. 1. - Location of the fluorspar district in Hardin and Pope counties, Illinois.

detect such geologic features as faults, fracture zones, and solution cavities that control the occurrence of fluorspar and associated sulfides. These geologic features alter the normal passage of shock waves in the earth and are therefore susceptible to detection by seismic methods.

During April and October of 1953, seismic surveys were conducted in three areas within the Rosiclare district. The areas were selected because they were accessible with the necessary equipment, landowners and lease holders were cooperative, and adequate subsurface control was available. The areas, outlined in figure 2, are as follows:

- 1) Goose Creek area, secs. 16, 17, 19, 20, T. 11 S., R. 9 E., northeastern Hardin County.
- 2) Hobbs Creek area, secs. 9 and 16, T. 12 S., R. 7 E., east-central Pope County.
- 3) Rosiclare area, sec. 5, T. 13 S., R. 8 E., south-central Hardin County.

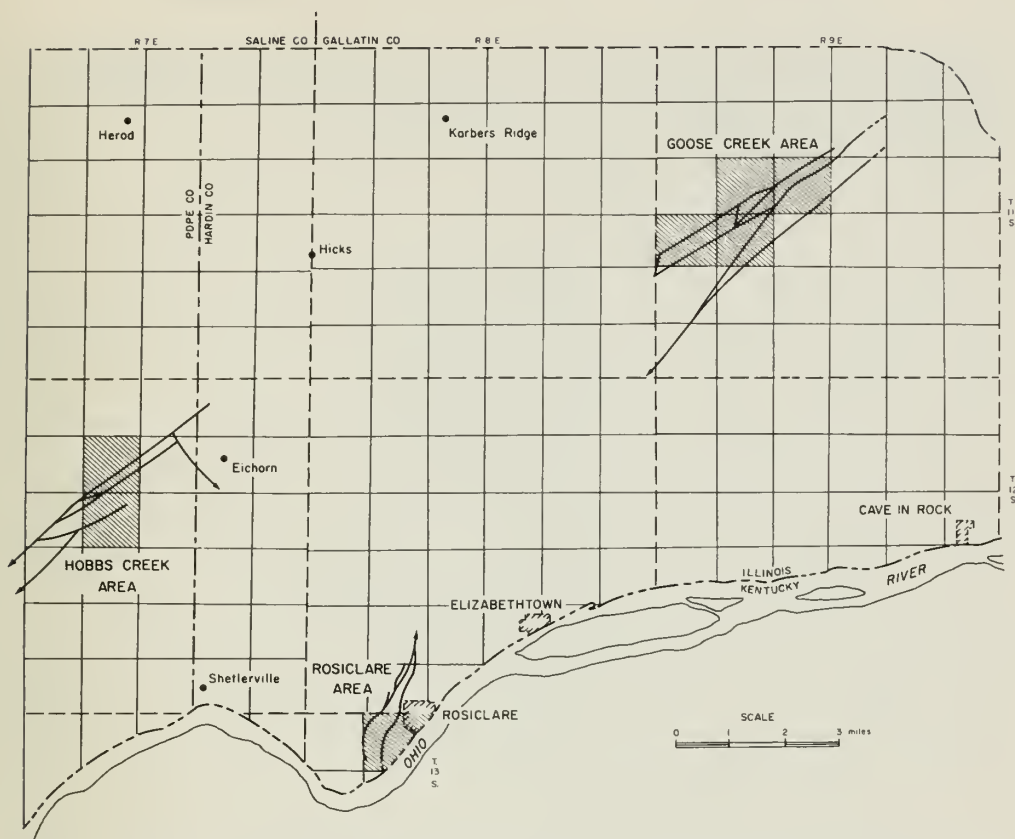


Fig. 2. - Hardin County and eastern Pope County showing seismic field test areas.

A report of the seismic investigations in the Hobbs Creek and Rosiclare areas will be presented later.

I wish to acknowledge the cooperation and the assistance of John C. Frye, Chief; M. M. Leighton, Chief Emeritus; George B. Maxey, and R. C. Parks of the Illinois State Geological Survey, M. W. Pullen, Jr., and D. B. Saxby, formerly of the Survey, and Harold Patton of the Goose Creek Fluorspar Mining Company in making this investigation possible.

GEOLOGY

The Illinois fluorspar district lies in hilly, unglaciated terrain in Hardin, Pope, and Saline counties. The district is bounded on the north and west by the Shawneetown fault and on the south and east by the Ohio River. The bedrock in the portions of the Goose Creek area in which the seismic field work was conducted is chiefly of Mississippian age. Part of the Station 65 profile was laid out over rocks of Pennsylvanian age on the southeast down-dropped block along the fault (fig. 7). Numerous faults have been mapped

from surface exposures and bore-hole information. The overburden in the area is thin and consists of residual, alluvial, or aeolian (wind-blown) material.

The geologic formations of Mississippian age which occur at the surface and in the subsurface of the area are as follows:

Mississippian System

Chester Series

Elvira Group

Kinkaid Formation

Degonia Formation

Clore Formation

Palestine Sandstone

Menard Formation

Waltersburg Sandstone

Vienna Formation

Tar Springs Sandstone

Homberg Group

Glen Dean Formation

Hardinsburg Sandstone

Golconda Formation

Cypress Sandstone

New Design Group

Paint Creek Formation

Bethel Sandstone

Renault Formation

Valmeyer Series

Meramec Group

Ste. Genevieve Formation

Levias Limestone

Rosiclare Sandstone

Fredonia Limestone

St. Louis Limestone

Salem Limestone

Osage Group

Warsaw Limestone

Osage Formation

Kinderhook Series

Upper New Albany Shale

Seismic investigations were conducted principally over formations of Chesterian age. The rock section included within these groups consists of interbedded limestones, sandstones, and shales. The cyclical depositional history of many of these formations has produced many similar lithologic units which may cause difficulty in mapping stratigraphy or logging cores. The changing lithologies, however, have value from the geophysical viewpoint because they provide the velocity contrasts necessary to structural mapping by the refraction method.

Certain of the sedimentary units have been found to transmit seismic shock waves at unique velocities. In such cases, seismic mapping of structure may be accompanied by the gathering of areal geologic data. This phase of seismic investigation in the Rosiclare district warrants further study as it may provide information otherwise unobtainable because of overburden or because of similarity of exposed rocks.

Of the three areas in Hardin and Pope counties in which seismic surveys were conducted, the Goose Creek area in secs. 16, 17, 19, and 20, T. 11 S., R. 9 E. of Hardin County (fig. 2) provides the most extensive and continuous subsurface structural control of a faulted area. The Goose Creek fault zone extends across the area in a northeasterly direction (fig. 6), the main structural trend of the entire Rosiclare district. The numerous diamond drill holes that have been drilled along the fault since 1950 have served to locate accurately the principal fault zone. The location and configuration shown here is altered slightly from that shown by Weller and others (Weller et al., 1952; Stonehouse and Wilson, 1955). The earlier work was based on scattered field exposures. The numerous faults in the area and the nature of the rock exposures make it difficult to do field mapping without some subsurface control.

As presently outlined by drilling, the Goose Creek fault is a faulted zone, locally more than 100 feet wide. It consists of a variable number of up-thrown and down-thrown blocks of different widths and displacements. At places, it is marked by a complexly faulted zone such as that shown in the geologic cross-section in figure 5 near the Goose Creek Fluorspar Mining Company shaft in sec. 17. The simpler structural conditions found along the fault are typified by the geologic cross-section shown in figure 7 near Station 65 (fig. 6).

The Goose Creek fault, therefore, is not a continuous single fault or group of faults. It is, rather, a faulted zone composed of many discontinuous faults of different lengths that extends across the area. The fault trace shown in figure 6 represents an average width and no attempt has been made to indicate the wider, more complex portions or the narrow, simpler portions. Drilling indicates that the direction of the faulted zone changes in sec. 17. There is not enough control to indicate whether the change of direction in sec. 16 is a bending of the faulted zone, as in sec. 17, or whether it represents an intersection with another fault such as that shown by Weller et al. (1952).

REFRACTION SEISMIC THEORY

The seismograph is an instrument which detects, amplifies, and records earth movements. When it is used for geophysical exploration, the seismograph records earth vibrations that are man-made and that are controlled with respect to magnitude of the initial shock, depth of origin of the shock, and space relationships between the source of energy and the vibration detectors.

Data from seismograph operations may be used to obtain depths to contacts between different types of rock or soil, to map the tops of certain subsurface marker horizons, and to locate concealed structural features other than the folded structures that were detected in mapping subsurface zones.

The concealed structures, such as the faults and fractures which may contain fluorspar deposits in the Rosiclare district, were of primary interest in the exploration conducted by the Illinois State Geological Survey. The interpretation of the seismic records has followed standard procedures set forth in the literature (Heiland, 1946). The study of wave passage through faulted rock zones presented by Ansel (1931) is of value in the interpretation.

In seismic work dynamite is commonly used as the source of earth vibrations. The shock energy from dynamite explosion is transmitted, or propagated, through the earth by waves which advance outward from the explosion (fig. 3). The waves travel through the earth at velocities that depend upon the types of rock or overburden through which they pass. Waves travel much faster through hard limestone than they do through poorly cemented sandstone or unconsolidated sands and gravels.

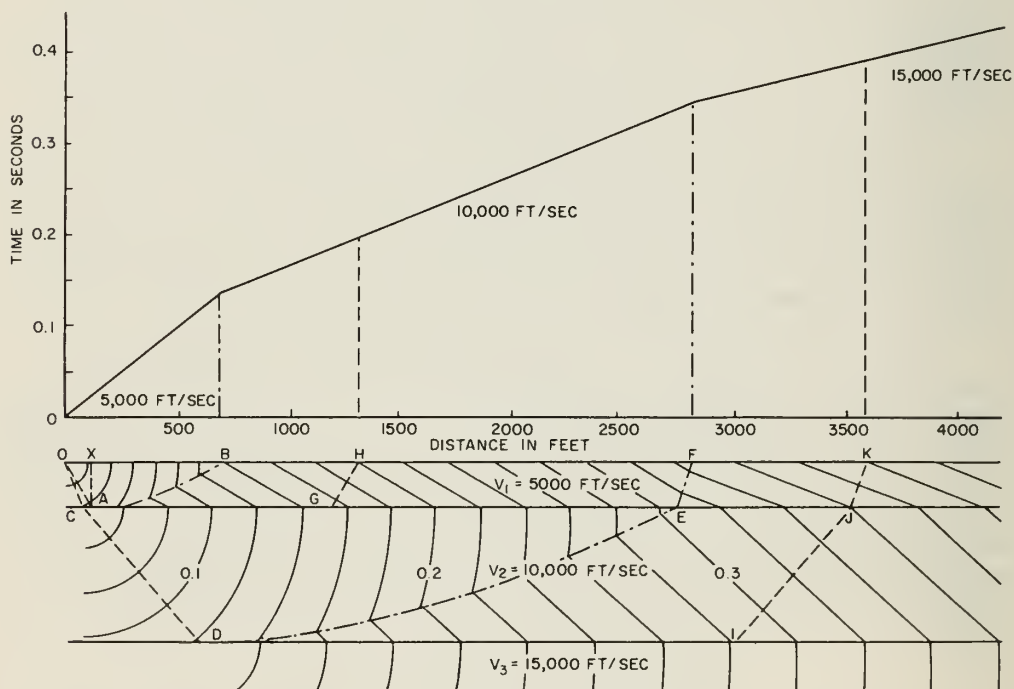


Fig. 3. - Wave-front diagram and travel-time graph. (After Johnson, 1954.)

In figure 3, waves are shown travelling through three layers having different wave-propagation velocities. At each contact, the direction of wave travel is changed or refracted, hence the name "refraction seismic method." Portions of the waves which originate at the dynamite explosion are reflected back toward the surface at the contacts between different kinds of rock. The reflected waves are not shown in figure 3, as they have not been used in the work described in this report.

The passage of waves through the subsurface layers may be recorded at the surface by sensitive detectors or geophones. As wave fronts or shock waves reach the surface, they cause the ground to vibrate, thus causing the geophones to move. The movement generates a small electrical current which in turn is amplified electronically and recorded photographically by the seismograph. Each rock layer permits passage of the shock wave at a velocity which is characteristic for that layer. Under the ideal conditions shown in figure 3, each velocity is detected at the surface by the geophones.

If enough geophones are placed on the surface, a sufficient number of shock-wave intersections at the surface will be recorded to permit construction of a travel-time graph such as that shown. The travel-time graph is a convenient way of graphically showing how rock layers have affected the passage of shock waves. Abnormal geologic conditions, such as the presence of faulted rock layers, produce disruptions in the orderly plotting of points on the graph. It is this feature of the refraction method and its travel-time graph which permits the detection of anomalous subsurface conditions (Heiland, 1946).

Refraction seismic data are usually presented in the form of the travel-time graph. The graph consists of a series of sloping lines which represent the rock layers through which the shock waves travelled from the dynamite to the detectors laid out on the surface of the ground. From the lines, one may obtain the velocities at which the different rock types transmitted the dynamite shock, the depths to the contacts between the rocks, and indication of structures which have impeded or disrupted the normal passage of the shock wave.

The objective of the seismic exploration in the fluorspar area has not been to obtain depths to the different stratigraphic units represented because the delineation of faulting, fracturing, and associated structures was of primary interest. The depths computed from refraction seismic records may be inaccurate in areas such as this where limestones that propagate the high velocity waves are interbedded with sandstone and shales that propagate the waves at slower velocities. The disruption of normal wave travel by faults also precludes accurate depth determinations throughout much of the area. The close association of the different rock types, however, does permit the accurate detection of faults because rock layers that transmit the waves at widely differing velocities are brought into adjacent and easily determinable positions by the fault displacements.

EQUIPMENT AND FIELD PROCEDURES

The equipment used by the Illinois State Geological Survey for the refraction seismic surveys in the Rosiclare district is a Century Model 506 seismograph. It is a portable, 12-trace instrument designed for refraction operations only. Wherever field conditions permitted, shot firing and data recording were conducted from within a vehicle. Mounting and electrical connection design have been so arranged as to permit rapid removal from the vehicle for completely portable operations. Figure 4 shows a portable set up at Station 64.

In the field, vibration detectors or geophones were arranged on the surface of the ground in a linear pattern or profile, as shown on figure 5. Twelve

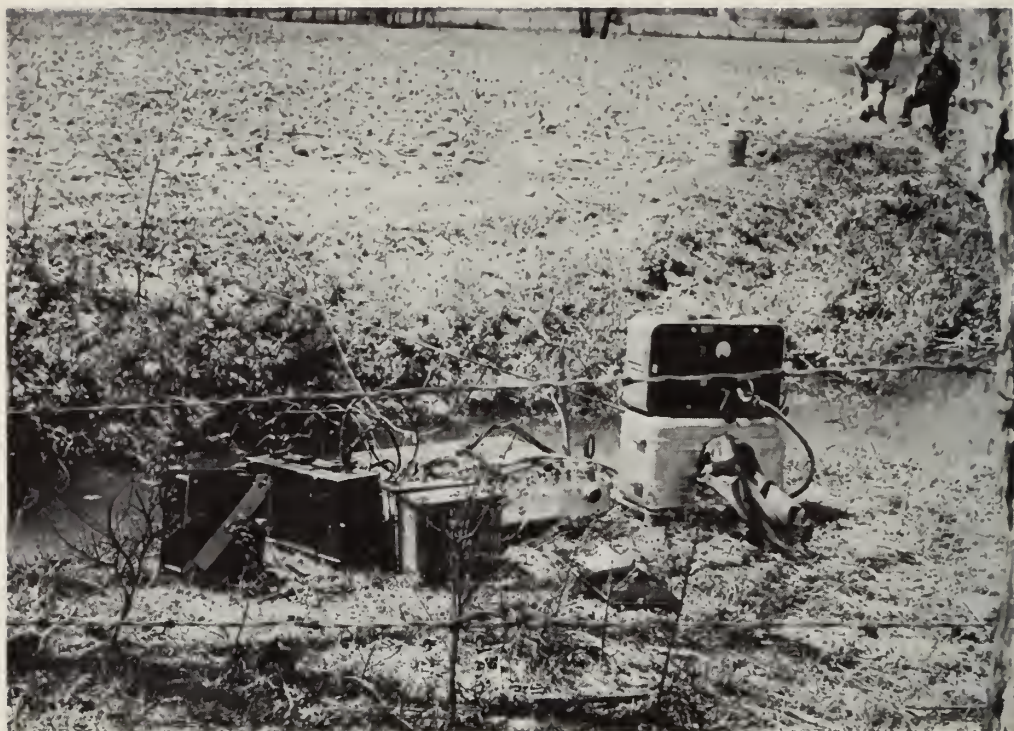


Fig. 4. - Portable seismograph equipment being used at Station 64.

geophones were laid out for each seismic station. The spacings between the geophones were altered in the field to best suit the topography and the known subsurface geology. The maximum spacing used between any two geophones was 50 feet.

The standard procedure of placing a dynamite shot at each end of a profile was adopted to provide maximum seismic data at each station. The two records obtained from this practice are shown plotted on the travel-time graph in figure 5. The dynamite shot holes were 2-inch diameter, hand-augered holes. No uniform depth was employed as the overburden varied considerably in thickness from place to place. The locally thin cover of one or two feet of soil over bedrock posed some hazardous firing problems. A more detailed description of the equipment and procedures may be found in an earlier Illinois Geological Survey publication (Johnson, 1954).

In the Goose Creek area, the field work was conducted over two extensively cored portions of the main Goose Creek fault in secs. 17 and 19 (fig. 6). Field correlation of the seismic data with subsurface structural interpretations, made by D. B. Saxby from core studies, justified further seismic exploration in the area. Stations 64 and 65 were located in sec. 16 along a possible north-eastward extension of the fault. Another exploratory seismic test was made in sec. 20 crossing an area in which surface geologic mapping has shown probable faulting.

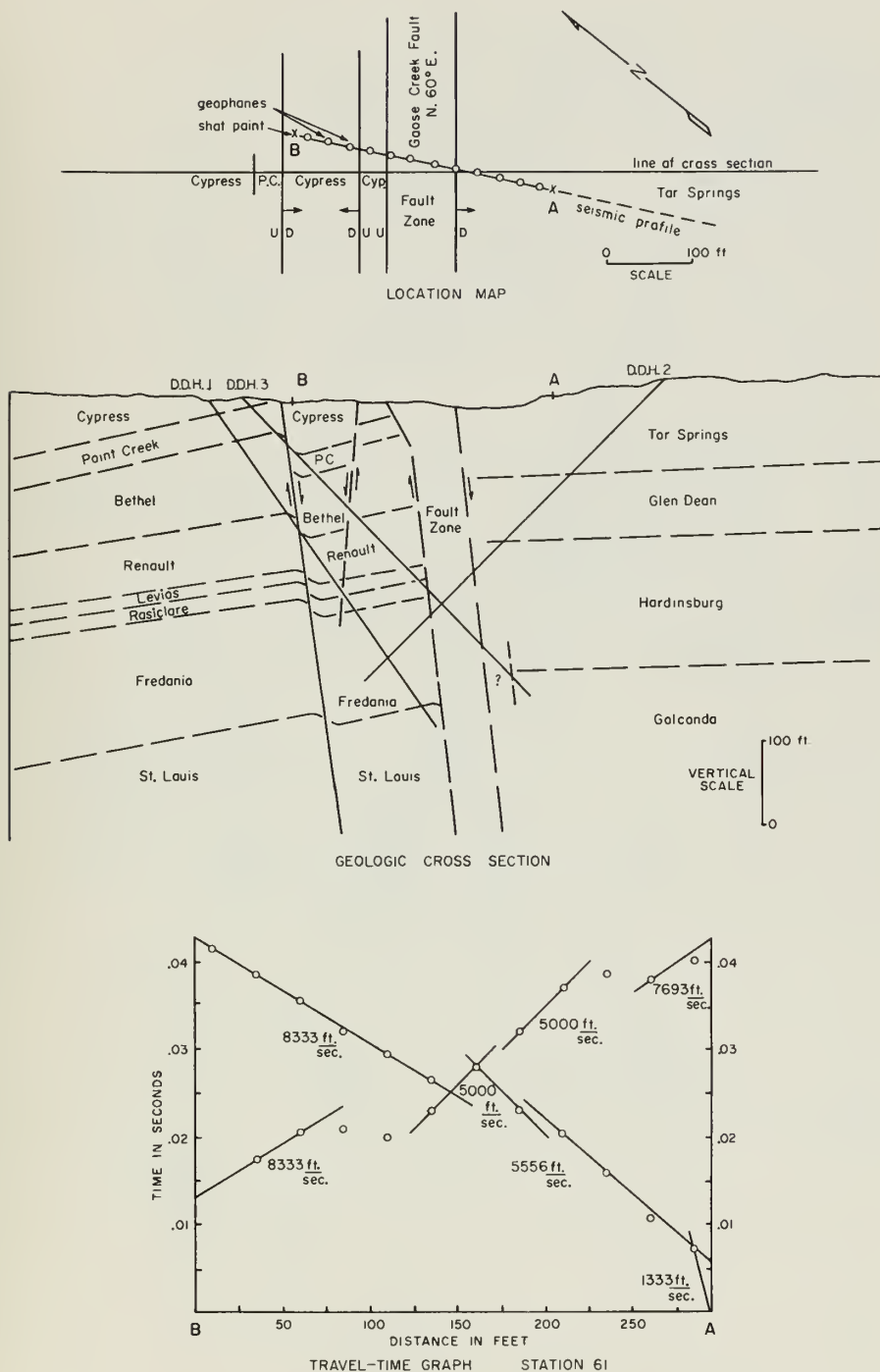


Fig. 5. - Location map, geologic cross section, and seismic travel-time graph, Station 61.

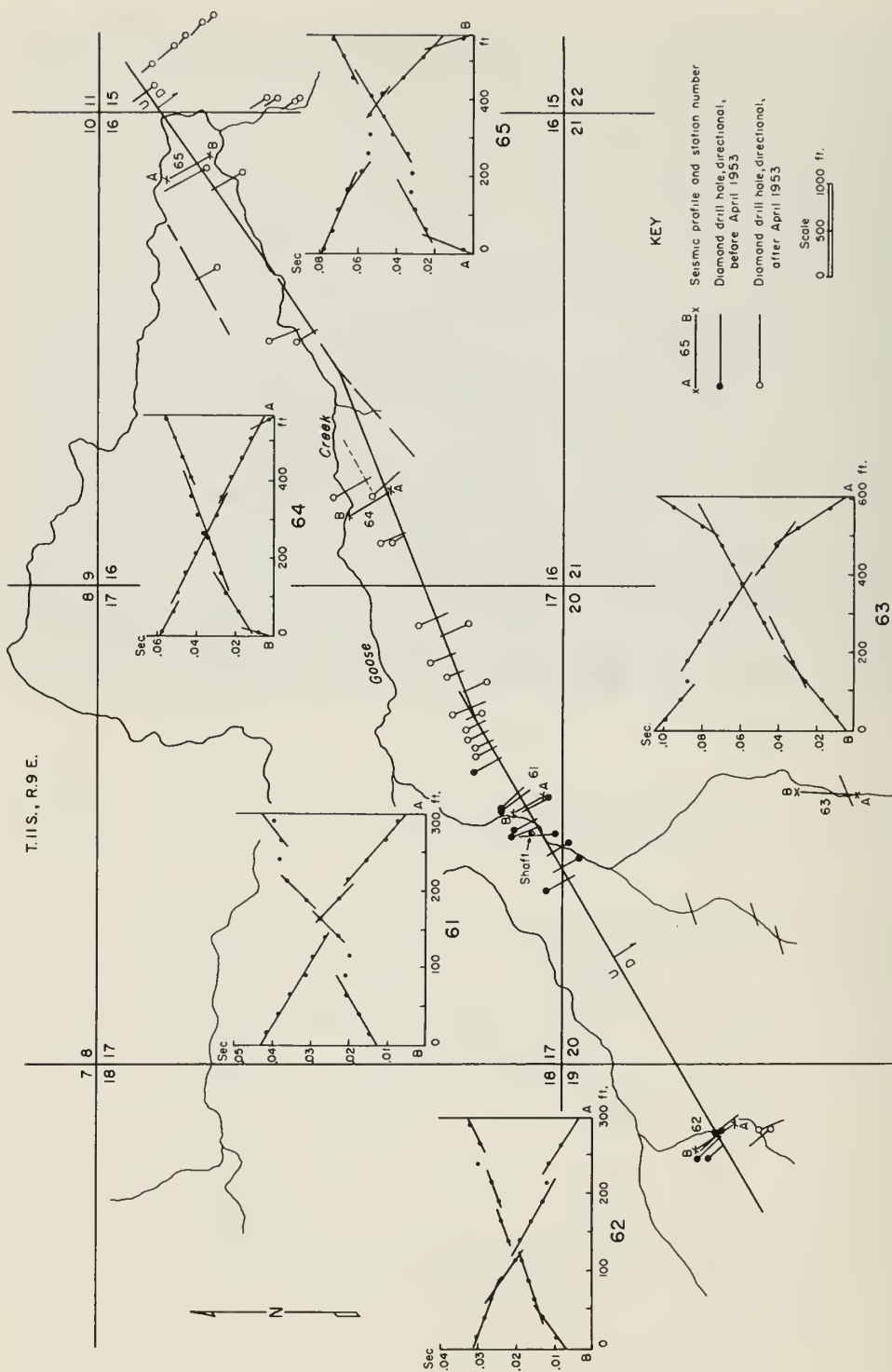


Fig. 6. - Goose Creek area showing Goose Creek fault, locations of diamond drill holes and seismic profiles.

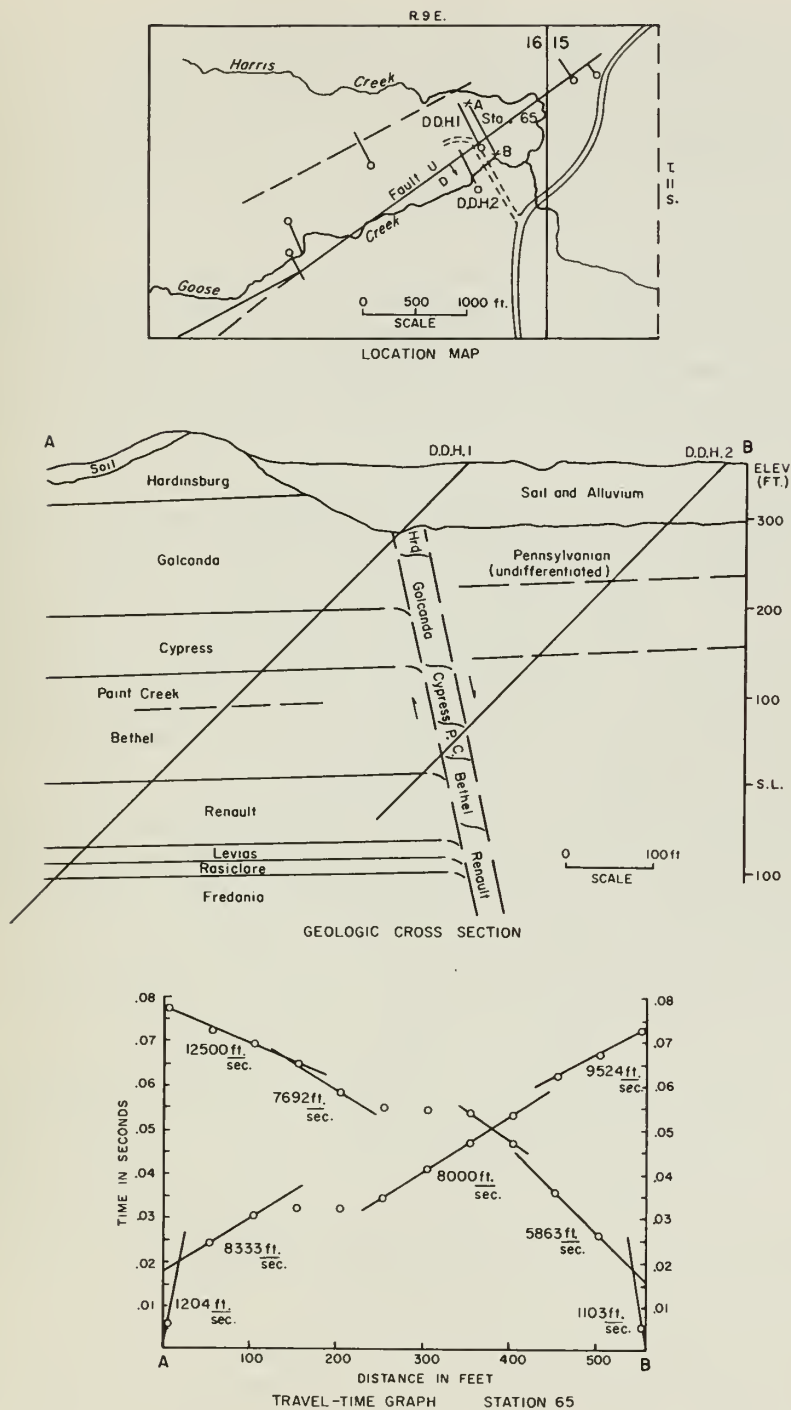


Fig. 7. - Location map, geologic cross section, and seismic travel-time graph, Station 65.

RESULTS OF SEISMIC INVESTIGATIONS

Exploratory core drilling had been done along the Goose Creek fault in the vicinity of the Goose Creek Fluorspar Mining Company shaft in sec. 17 (fig. 6) and along the fault extension in sec. 19 by the time that seismic operations were conducted by the Illinois State Geological Survey. Drilling northeast of seismic Station 61 was in progress in sec. 17. Prior to this geophysical investigation, there had been no drilling information released for the area in sec. 16 along the fault.

With drill-hole information as a guide, seismic Stations 61 and 62 were located and the field layouts so arranged as to cross the main Goose Creek fault zone. The interruption of the normal passage of the dynamite shock waves by the closely spaced faults and the complex fault zone at Station 61 is shown in fig. 5. Comparison of the travel-time graph in figure 5 with the geologic cross section indicates how the travel-times depart from the ideal conditions shown in figure 3.

It is apparent from examination of the graph that the amount of time departure caused by a fault need not have any correlation with the amount of fault displacement. Such conditions are the result of many factors, among which are: the direction of fault dip; the altered positions of different types of rock layers; the complexity of the fault zone and the placement of the dynamite shot relative to the fault (Dix, 1939). With the seismic work in the area as a basis, the complexly faulted rock zone within the main fault zone may not cause any greater disruption in the transmission of the shock waves, at least in one direction, than do the more simply or more cleanly faulted blocks which at Station 61 are associated with the complex area.

Although it is difficult or impossible for one to calculate the amount or direction of fault displacement in this area of cyclically deposited sediments, the presence of faulting is clearly shown by the discontinuous velocity lines in the travel-time graph. The abnormal conditions indicated on the graph for Station 61 (fig. 5) are striking in comparison with the ideal type of travel-time graph obtained by refraction shooting in an unfaulted area (fig. 3).

The Goose Creek fault or fault zone, as outlined by diamond drilling, is shown in figure 6. The extensive drilling in secs. 17 and 19 previous to the investigations provided excellent subsurface geologic control.

The seismic results obtained at Station 61 have been compared to geologic data in figure 5 and also have been placed on figure 6. The geologic conditions at Station 62 in sec. 19 are less complex than at Station 61. At Station 62 a normally faulted area about 80 feet wide with four discrete fault surfaces and recognizable stratigraphic units between them replace the wide, closely faulted and locally shattered fault zone encountered at Station 61. The character of the travel-time graph at Station 62 is notably different from that at Station 61 as the result of the changed structural conditions.

The seismic operations were extended northeastward along the probable extension of the fault as the result of the correlation between the seismic velocity discontinuities and the known structure at Stations 61 and 62. The locations and travel-time graphs for the two seismic profiles (Stations 64 and 65) are shown on figure 6. None of the diamond core holes proving the location of the fault in either of the two areas had been drilled at the time.

The travel-time graph constructed from seismic records obtained at Station 64 does not indicate the closely spaced, complex faulting common to Station 61. The anomalous portions of the travel-time graph bear more similarity to the simpler, more cleanly faulted zone encountered at Station 62. At Station 64, there would appear to be only two faults of unknown displacement under the field layout of the geophones. The simplicity of the anomalies would rule out a faulted zone composed of several closely spaced faults, if the results obtained at Stations 61 and 62 may be used as criteria.

Four diamond drill holes were made later near Station 64. They were located much on the basis of the seismic results. The drilling has shown that the seismic profile did not extend far enough to the south to intercept the typical multiple faults of the Goose Creek fault which were encountered during drilling. Surface topographic features of the fault near Station 65 indicated that there would be a slight eastward bending of the fault a short distance north-east of the shaft and Station 61. In the absence of drilling, we thought that the layout at Station 64 would straddle the zone. The eastward deflection of the faulted zone was greater than expected. Subsequent drilling has shown that a northward bending or intersection with another fault exists about 2000 feet northeast of Station 64. There are no indications of this in the valley floor of Goose Creek and our projection of the fault between Station 61 and the vicinity of Station 65 was north of the actual position of the fault.

The indications of faulting on the graph probably resulted from minor faults associated with the main faulted zone. Only one of the drill holes showed evidence of displacement within the distance covered by the seismic profile. The position of the fault is shown on the drill hole projection east of the profile on the map. The strike is not known from the drilling and is drawn on the map only for purposes of presenting the fault pictorially. Seismic data would substantiate the strike as shown. The drill cores and the seismic data at Station 64 illustrate the discontinuous nature of the faults that make up the Goose Creek fault. Core studies in the Illinois State Geological Survey files show that the faults which compose the main Goose Creek fault are difficult to trace from one drill hole to another, even in such closely drilled areas as this. There are no corroborating core data for the travel-time graph anomaly in the north part of the profile at Station 64.

The seismic field layout for Station 65 was based upon the probable topographic expression of faulting referred to in the preceding discussion. The Goose Creek valley wall on the northwest side of the stream near Station 65 resembles a fault or fault-line scarp. Its linear appearance guided our placement of the equipment. None of the drilling shown in figures 6 and 7 had been done at the time of the survey.

The travel-time graph of Station 65 (fig. 7) has an anomalous section which indicates considerable alteration of normal wave travel. Comparison of the graph with that for Station 61 shows similarity with the seismic discontinuities produced by both the complex fault zone and the simple faults. Although the exact nature of the subsurface structural conditions could not be interpreted from the data, we considered that the seismic indications of a fault or faults between the ends of the profile were sufficient proof of their existence.

Subsequent drilling, located on the basis of the seismic survey, in the NE 1/4 of sec. 16 has shown the structural picture to be that reproduced in the geologic cross-section of figure 7. Faulting consists of two normal faults 30 to 40 feet apart, the southernmost one having a considerable vertical displacement with Pennsylvanian age rocks down-thrown adjacent to Mississippian age rocks belonging to the Chester series. Northeast of Station 65 in sec. 15, the main faulted zone is about 70 feet wide and is characteristic of the Goose Creek fault at Station 61. In the distance from diamond drill hole No. 1 in sec. 16 to the drill holes in sec. 15 shown on the location map of figure 7, the fault zone becomes twice as wide and includes a complex zone as at Station 61. The change in character of the faulting between the drill holes probably is the cause of the similarity of the travel-time graphs for Stations 65 and 61. The Station 65 profile was located between these two areas of drilling and shows the gradation to more complicated structural conditions.

In the Goose Creek area, a seismic profile was made at a location south of the Goose Creek fault in sec. 20. Earlier work by Weller and others (1952), and later field work by Illinois Geological Survey geologists had indicated that at least one fault passed through the area which is bracketed by Station 63. Its location is shown crossing the profile. Nearby diamond core drilling had also shown that we might expect faults in the area.

The discontinuities obtained on the graph for Station 63 indicate the presence of several faults or zones in which the passage of the shock wave was altered. As for Station 65, it is difficult to interpret the subsurface conditions. Closest similarity with the seismic results obtained along the Goose Creek fault was obtained at Station 63 where we shot over a cleanly and simply-faulted area. The cause of the abrupt change in wave velocity near the south end of the profile is unknown. It may be caused by alluvial fill in an old channel of the stream which is adjacent to the profile, as the low velocity of 3000 ft./sec. is much less than that obtained from any consolidated rock in the area and is more in line with elastic wave transmission velocities of the alluvium. In a limestone area such as this, in which there are many scattered sink holes, it is possible that the south or "A" end of the profile was placed over a buried sink or the residual soil fill of a solution depression.

SUMMARY AND CONCLUSIONS

The refraction seismic method is shown to be useful in determining the location of concealed faults in bedrock areas. This is of special value in the Rosiclare fluorspar district where the fluorspar mineralization is associated with faults and fractures in the rock. The combination of seismic information with surface and subsurface geologic control, may well be used to determine where to locate exploratory drill holes in the district. The seismograph does not locate fluorspar deposits, but it may aid in locating areas that have structural conditions favorable to their occurrence.

At present, there has not been enough refraction seismic exploration in the district to permit detailed interpretation of the structural conditions. Faults cause definite discontinuities in segments of the travel-time graphs. Drill-hole data show that the location of faults in areas where we had no geologic control has been correctly interpreted from the seismic records. The

amount and direction of the displacement, the dip of the fault surface, and the relative complexity of the faulting is more difficult to determine. In time, we may compile sufficient geologic and seismic information in the district to be able to predict the relative complexity of a faulted zone, but the local stratigraphy will probably preclude any consistently correct interpretations about the type of fault, the amount of displacement, or the dip.

In exploration for faults, it would be advisable to alter field methods to permit continuous profiling of an area rather than the spot checking procedure described in this report where we had, for the most part, prior knowledge of subsurface conditions. In continuous refraction profiling, the seismic data along a long traverse may be used for interpretation of the records from any part of the traverse which may produce anomalous information.

Continued experimentation and exploration with the refraction seismograph throughout the Illinois-Kentucky fluorspar district is warranted. Such a program, with the cooperation of the public and private groups involved in the exploration and development of fluorspar resources, will be of economic value to the companies and the population of the district.

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